

## REMARKS

Claims 1-29 are pending in the application. Claims 1-29 are subject to restriction. The Examiner made three groups, Group I (claims 1-7), drawn to a method for producing a replication master, Group II (claims 8-18), drawn to a replication method, and Group III (claims 19-29), drawn to a replication master.

Amendments are made to independent claims 1, 8, 10, and 19. In particular, the "smoothing" layer is clarified in claims 1 and 19, and the literal elements of claim 1 are added to claim 8, so that it no longer relies on any other claim. Claim 10 is amended to correct a typographical error.

### ELECTION:

The Applicant elects Group II, claims 8-18.

### WITH TRAVERSE:

The Applicant traverses the present restriction as being improper under PCT Rule 13, which describes the Unity of Invention.

Including three related independent claims is specifically authorized as under the PCT Unity rules, as described in the MPEP

Unity can exist in a single application that contains independent claims to a product, a method for making the product, and a method for using a product, as addressed in MPEP 1893.03(d) and MPEP 1850 III.A(A), which specifically states:

The method for determining unity of invention under PCT Rule 13 shall be construed as permitting in particular, the inclusion of any one of the following combinations of claims of different categories in the same international application:

(A) In addition to an independent claim for a given product, an independent claim for a process specially adapted for the manufacture of the said product, and an independent claim for a use of the same product; (MPEP 1830 III.A(A)) (Emphasis added)

The Examiner's own characterization of the claims in the restriction requirement fit this scenario exactly. The independent claims include:

- a) "a given product" (Claims 19-20 "*drawn to a replication master*");

b) "a process specially adapted for the manufacture of the said product" (Claims 1-7 "*drawn to a method for producing a replication master*"); and

c) "a use of the same product" (Claims 8-18 "*drawn to a replication method*").

Thus, the Unity of invention is preserved even though three separate independent claims are included in the same application, as MPEP 1830 specifically permits such an application.

The Unity of Invention standard is different than standard US Restriction practice

The Standard for Unity of Invention under the PCT differs from standard US Restriction practice. The confusion between the two prompted the MPEP to include, as one of the first paragraphs of MPEP 1893.03(d):

Examiners are reminded that unity of invention (not restriction practice pursuant to 37 CFR 1.141-146) is applicable in international applications (both Chapter I and II) and in national stage applications submitted under 35 USC 371. (MPEP 1893.03(d))

The present application is a national stage application, and thus the Unity of Invention Rules apply.

The International Searcher and European Examiner found Unity in the International Application

The present application is a US National Stage application from an original PCT application PCT/EP2004/053158. Both the International Searcher and the European Examiner have analyzed the exact same claim grouping as in the present application, and each of them has independently concluded that Unity exists in this case with three independent claims.

The '158 PCT application matured into European Patent EP 1,535,712B1, which was granted January 14, 2009. The European Patent is attached as Appendix A to this response.

Note that the granted '712 European Patent includes claims directed to:

- Method for producing a replication master (Claim 1);
- Method for producing a smooth object using a replication master (Claim 5);and
- A replication master (Claim 16).

Two separate patent professionals have reviewed the pending claims using the PCT Unity of invention rules and found Unity in this case. This is strong evidence that the US Examiner is applying a different, more restrictive, standard for Unity than the proper standard. It is respectfully requested that the Examiner reverse the holding that Unity is not present in this case, especially in light of an issued European counterpart patent that issued with claims directed to the same subject matter as in the present application.

#### Common Technical Feature

The Examiner exclaims that the common technical feature of the pending claims is “a replication master having a low surface roughness, an external surface shape which at least partially corresponds to a counterform of a surface of an object, wherein at least a part of the master is coated with a smoothening layer made of a soluble material,” and then states that this feature was known in the prior art as evidenced by Skinner, US 4,690,370.

Skinner was known to the Applicants and was submitted to the USPTO in an IDS upon filing the present application.

#### Skinner contains a **smooth** layer, not a **smoothening** layer

A copy of the response to the European Examiner referring to Skinner was supplied as IDS materials and are part of the application wrapper. As described to the European examiner, who ultimately allowed the European patent EP 1,535,712B1 to issue with claims similar to those that are now pending in the present case after amendment, Skinner teaches providing a smooth surface coating 34 on a surface portion 32 of a mold 24. The surface coating 34 may be made by sputtering, as taught in column 2, line 16 of Skinner.

Skinner repeatedly emphasizes that the roughness on top of the surface coating 34 is exactly identical to the roughness of the surface portion 32 on which it has been grown. For example, Column 1, lines 57-65; Column 2 lines 13-19, column 4, lines 20-31, as well as in claims 1 and claim 4 of Skinner.

All of these passages repeatedly point out that the surface roughness values of the surface portion 32 and its surface coating on top 34 are absolutely identical --  $12.5 \times 10^{-8}$  meters RMS. Thus, the surface coating 34 is not a “smoothening layer” in that it is not smoother than its underlying layer, but rather surface coating 34 is a smooth layer because its underlying layer is already smooth.

Skinner, in Column 4 lines 26-31 makes clear that the surface roughness value of the “substrate” is obtained “by smoothing the surface portion 32 of the mold 24 until it has a roughness of no more than about  $12.5 \times 10^{-8}$  meters RMS.

When this roughness value is obtained, the surface coating 34 is grown on the surface portion by sputtering, but the smoothness of the surface coating 34 is not more smooth than the substrate.

In other words, the surface coating 34 proposed in Skinner is smooth (at least in the sense of Skinner’s purposes) because it is grown on an already-smooth substrate, but Skinner’s surface coating 34 is not a “smoothing” layer as taught by and claimed in the invention.

Claimed embodiments of the invention include a smoothing layer

Claimed embodiments of the invention, conversely, specifically provide a layer that provides a smoothing function, which, due to flowability of the material, displays a smaller roughness at its top surface than the surface on which it has been grown, as included in independent claims 1, 8, 19, and as described in the application specification on page 3, lines 4-19.

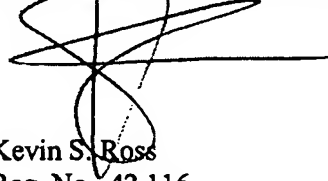
Unity is preserved by the common technical feature

As illustrated in the above passages, there is a common technical feature of a replication master that is coated with a smoothing layer having a particularized flowability. As this common technical feature is included in each of the independent claims, and the PCT Unity of Invention rules allow for multiple independent claims to be within a single national stage patent application provided there is a common technical feature, as specifically described in the cited MPEP passage above, the Applicant respectfully requests that the Examiner reconsider the position on Unity, and agree that Unity exists in the present application.

The Examiner is encouraged to telephone the undersigned at (503) 222-3613 if it appears that an interview would be helpful in advancing the case.

Respectfully submitted,

MARGER JOHNSON & McCOLLOM, P.C.

A handwritten signature in black ink, appearing to read 'Kevin S. Ross', is written over the firm name.

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(54) **Method for producing a replication master, and replication master**

Verfahren zur Herstellung einer Abformungsmatrize, sowie Abformungsmatrize

Procédé de fabrication d'une matrice de reproduction par moulage, et matrice de reproduction par moulage

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**US-A- 5 838 506** **US-A- 5 855 966**

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**EP 1 535 712 B1**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

## Description

[0001] The present invention relates to a method for producing a replication master having a surface with low roughness, comprising the steps of forming said master such as to have a desired external surface shape which at least partially corresponds to a counterform of a surface of an object to be produced by replication, and treating said external surface of said master to obtain a predetermined surface roughness value.

[0002] Such a method is for example known from document US 4,525,853 which discloses a method according to the preamble of claim 1 and a master according to the preamble of claim 16. This document describes the case of a replication master which is to be used for producing an X-ray focussing mirror comprising a plurality of layer pairs for reflecting and simultaneously focussing X-rays.

[0003] As described in this prior art document, the master is made from a metal material resembling a cone, the external surface shape of which corresponds to the curved counterform of the surface of the mirror to be produced by replication.

[0004] This replication process which follows the preliminary production of the replication master essentially comprises coating the master with suitable mirror materials, for example by molecular beam epitaxy (MBE) deposition or other deposition methods well-known in the field of monolayer or multilayer production.

[0005] As is also well-known, the master surface on which these layers are grown, has to be as smooth as possible in order to grow smooth layers having a low surface and interface roughness which negatively effects the mirrors reflectivity.

[0006] In order to provide the master surface with the desired shape, namely the counterform of the object to be produced, and to simultaneously reduce the roughness of the master surface the prior art therefore proposes to treat the master surface by diamond turning. As is well-known, diamond turning leads to surfaces which look smooth on a macroscopic scale, but today the optimum roughness obtainable by this method is in the order of 20 Angströms (root mean square, rms) and thus still much too high to deposit monolayers, bilayers or multilayers for optical purposes on such a master like for example for producing X-ray optics and other high performance optics. In general, it is desired to deposit monolayers on a substrate having a roughness of not more than approximately 5 Angströms in order to limit the surface roughness of such monolayers. For the deposition of bi- or multilayers, one has to take into account that the interfacial roughness between consecutive layers may increase, so that the surface of the topmost layer will have a roughness which significantly exceeds the roughness of the substrate on which the entire assembly is deposited. It is therefore in general desired to use substrates having a surface roughness of less than approximately 5 Angströms (rms) for the deposition of bi- or multilayers.

[0007] The prior art therefore proposes a second kind of surface treatment to be applied, namely mechanically polishing the diamond turned master surface. This mechanical polishing can reduce the roughness of the master surface to values of approximately 5 Angströms or less, so that the master can then successfully be used for the production of optical components by replication.

[0008] However, the necessary polishing or superpolishing operation is extremely time-consuming, difficult and therefore expensive.

[0009] It is therefore an object of the present invention to improve a method for producing a replication master as known from the prior art in such a way that a roughness of the master surface in the order of only some Angströms can be obtained without any mechanical polishing.

[0010] According to the invention this object can be achieved when said method comprises the step of coating at least a part of said master with a smoothening layer according to claim 1.

[0011] This smoothening layer is a layer which due to a certain flowability of its material displays a smaller roughness at its top surface than the surface on which it has been grown, in contrast to for example ordinary metallic monolayers, the surface of which usually displays a larger roughness than the surface of the substrate on which they have been grown.

[0012] Thus, according to the invention a diamond turned master surface having a roughness of approximately 20 Angströms can be coated with such a smoothening layer displaying a roughness of only 5 Angströms or less after the end of the coating step. The surface of the smoothening layer then forms the new smooth master surface.

[0013] Advantageously, said smoothening layer is applied by dip-coating or spin-coating a liquid smoothening material on said master and hardening said smoothening material. Dip-coating and spin-coating are well-known technologies and will therefore not be described in detail. It should, however, be pointed out that these coating techniques are much less time-consuming to realise than the polishing or superpolishing techniques proposed in the prior art.

[0014] As is well-known in the field of replication, and for example also explained in the above-discussed prior art document US 4,525,853, the object to be produced by replication is formed on the smooth master surface and has to be released at the end of the production operation. In an embodiment, the method according to the invention can therefore comprise the step of coating at least a part of said master with a release layer. This release layer is then chemically or mechanically removed when production of the object is terminated, so that contact between the master and the object gets lost and the cone-shaped master can be pulled out of the surrounding object. In case the release layer is deposited on top of the smoothening layer, the master can therefore be recovered with the smoothening layer still being on top of the master surface, so that the smooth master can im-

mediately be re-used for the production of another object in a next replication cycle.

[0015] However, it is also possible to provide the release layer between the master core and the smoothening layer. In this case only the core of the master will be recovered, whereas the smoothening layer will stick to the object separated from the master. The smoothening layer may then have to be removed from the object.

[0016] In an advantageous embodiment, the smoothening layer takes over the role of the release layer thus preventing from the coating of a release layer.

[0017] In a particularly advantageous embodiment said smoothening layer and/or said release layer is made of a soluble material, in particular a soluble polymer material, for example a PMMA photoresist. At the end of the object production process, the object can then easily be separated from the master by immersing the master with the object on top in a suitable solvent. In case of a smoothening layer and/or release layer made of a PMMA photoresist, acetone can be chosen as such a suitable solvent.

[0018] In all the above-described embodiments, the method for producing a replication master according to the invention leads to a master having an extremely smooth surface, which is formed either by the smoothening layer or the release layer, so that one can then easily continue the method for producing the replication master to a complete replication method for producing a smooth object having a low surface roughness, comprising the steps of producing a replication master by a method according to any of the above-discussed embodiments, coating at least a part of said master with an object material such that the surface of said object corresponds to a counterform of said master, and releasing said object from said master.

[0019] The releasing step can in principle be executed by cooling the master so that it shrinks more than the surrounding object.

[0020] Advantageously, however, said releasing step comprises dissolving said smoothening layer and/or said release layer on top of said master by a solvent. As already explained above, acetone may be chosen as a suitable solvent for example in the case of a smoothening layer and/or a release layer made from a polymer material, for example a PMMA photoresist.

[0021] No matter how the releasing step is realised, it leads to the separation of the master from the object produced by replication. In case of optical components to be produced, for example reflective multilayer mirrors for X-rays, EUV or IR or synchrotron radiation, laser light or neutrons, the object may be too thin and fragile to be used as a stand-alone device. It is therefore advisable to transfer the object produced on the master to a kind of substrate before separating it from the master. An advantageous improvement of the replication method for producing the smooth object according to the invention therefore comprises the step of providing glue to said object and/or to an object support and gluing them to-

gether before executing said releasing step. By doing so the object can be stably transferred to the object support before executing the releasing step, i.e. before separating the object from the master. In the above-discussed case in which the releasing step comprises dissolving the smoothening layer and/or the release layer by a solvent, this means that the entire set-up of the master with the newly produced object on top and the object support glued to them is immersed into the solvent. In this case it is of course important to make sure that the glue itself is not attacked by the solvent in order not to lose the stable contact between the object and the object support.

[0022] The amount of glue used in this embodiment can be chosen such as to fill gaps between said object and said object support. This leads to the following advantage provided by the method according to the invention:

[0023] Replication methods used for producing optical devices are usually based on cone-shaped replication masters onto which the optical device, i.e. the object, is grown. One can imagine the object as a kind of circumferential "skin" of the cone-shaped master, which then has to be transferred to the object support. Usually the object support therefore has to be rather precisely pre-shaped to have an external shape which more or less corresponds to the counterform of the object. This involves preliminary machining steps during the production of object supports, and in particular different kinds of object support have to be prepared for different kinds of objects to be transferred to these supports, e.g. objects having different sizes. With the above-proposed possibility of choosing the amount of glue such as to fill gaps between the object and the object support, it is sufficient to less precisely preshape each individual object support or even to only provide one type of object support corresponding to the largest type of object, and smaller objects can be carried by such an object support, e.g. in a recess of the support, by simply filling more glue into this recess.

[0024] As already mentioned before, in one embodiment of the replication method according to the invention, said object is an optical device, e.g. a reflection or transmission monolayer, bilayer or multilayer. Without any limitation, one can e.g. mention Au monolayers, W/Si multilayers, Pt/C multilayers, Mo/Si multilayers etc. as such optical devices, which are commonly used in X-ray, EUV or synchrotron scattering applications, for example macromolecular X-ray crystallography or X-ray diffraction analysis.

[0025] Even though the method according to the invention allows to obtain a smooth master, and the subsequent steps of the replication method for producing the object are in principle well known, exceptional disturbances may occur either during coating the master with the smoothening layer or during the subsequent deposition of the object on the smoothened master surface. Regardless of whether these disturbances are mechanical or chemical in nature, they will negatively affect the surface profile of the object and/or its optical behaviour.



It would of course be extremely inefficient to discover e. g. a disturbance due to an irregular smoothening layer only after having released the entire finished object from the master. In a further development it is therefore proposed that the replication method according to the invention furthermore comprises the step of characterising said optical device on top of said master before executing said releasing step, wherein said characterisation step may e. g. comprise performing a profilometry and/or a reflectometry measurement of said optical device. Whereas profilometry analyses the surface shape of the object, reflectometry will directly yield information about its optical behaviour. Such a characterisation should be made when a multilayer object is finished and it can even be made after the first few layers of the multilayer object have been deposited on the master surface. If during this characterisation important disturbances are observed, one can immediately interrupt the further production of the object, separate the object as it is at that time from the master and start a new replication cycle. In other words, one can e. g. coat the master with a fresh smoothening layer and restart the deposition of the first layers of the multilayer object, thus avoiding unnecessary production steps in order to save time and cost. This is particularly advantageous when the releasing step is executed chemically by means of a solvent dissolving the release layer or the smoothening layer which in this case simultaneously takes over the role of a release layer. Indeed one may increase the life time of the master compared to a mechanical releasing step.

[0026] The latter embodiments were based on the assumption that the object deposited on the master is the optical device to be produced itself. In an alternative embodiment of the replication method according to the invention, however, the object can be a substrate for an optical device. In this case the replication method serves to produce an extremely smooth substrate. By means of the above-discussed transfer step of providing glue to the object and/or to an object support and glueing them together before releasing the object from the master, this extremely smooth substrate can be stably transferred to an object support which in this case takes the role of a substrate holder. This extremely smooth substrate produced by replication may then be used for the deposition of an optical device like e. g. an X-ray multilayer by well-known deposition methods. In order to avoid any complications due to incompatible materials or in order to reduce the number of steps it is then recommended that the object material and the material of said glue are identical. In this case it may be completely sufficient to coat the smoothened master with a thick layer of glue and to attach the thus prepared master with the glue layer on top to an object support. After hardening of the glue and removal of the smoothening layer and/or the release layer and subsequent removal of the master, the object support will have an extremely smooth substrate made from hardened glue on top, the external shape of which corresponds to the counterform of the smoothened master

surface.

[0027] Advantageously said object material and said glue comprise epoxy resin. This material can be easily applied to the smoothened master surface and/or the support surface in its liquid state, and after hardening it will serve as a stable substrate on which an optical multilayer may be deposited.

[0028] In a further development of this latter embodiment, in which the replication method according to the invention is used to produce an extremely smooth substrate, the method may furthermore comprise the step of coating at least a part of said master with a protection layer on top of said smoothening layer or release layer before applying said object material. This option may in particular be taken advantage of if there is a risk that the smoothening layer will be negatively affected by direct contact with the epoxy resin or other glue or that the epoxy resin or other glue may be attacked by the solvent. The protection layer can therefore be used to protect the epoxy resin or other glue during the releasing step and subsequent deposition steps. This protection layer may e. g. be a thin metal layer. As it is directly deposited on the smoothening layer or on the extremely smooth release layer, it will also display an extremely low surface roughness on its top surface, so that it also represents a smooth substrate for the further deposition of an optical device after the releasing step.

[0029] The invention furthermore relates to a replication master for producing a smooth object having a low surface roughness, said master having an external surface shape which at least partially corresponds to a counterform of a surface of said object, characterised in that at least a part of said master is coated with a smoothening layer.

[0030] As explained above, this replication master can be produced by the method according to the invention. Such a smoothened replication master can in general be used for any kind of replication production method without any limitation to the field of optical devices or other monolayers, bilayers or multilayers.

[0031] Furthermore, such a replication master according to the invention can at least partially be coated with a release layer in order to facilitate release of a future object produced by replication from the master itself.

[0032] Finally, in an advantageous embodiment said smoothening layer and/or said release layer is made of a soluble material, in particular a soluble polymer material, for example a PMMA photoresist.

[0033] In the following some advantageous embodiments of the method according to the invention will be illustrated with reference to the accompanying drawings in which:

figure 1 shows a perspective view of an ideal cone-shaped replication master;

figure 2 shows a perspective view of a corresponding object support;

figure 3a shows a perspective view of a real replication master having a rough surface;

figure 3b is a front view of the broad end of the master in figure 3a;

figure 4a is a schematic perspective view of the master in figure 3a after coating with a smoothening layer;

figure 4b is a front view of the broad end of the master in figure 4a;

figure 5a is a schematic perspective view of the master in figure 4a after additional coating with an optical monolayer;

figure 5b is a front view of the broad end of the master in figure 5a;

figure 6a is a schematic perspective view of the master in figure 5a glued to the object support in figure 2;

figure 6b is a front view of the broad end of the master and object support in figure 6a;

figure 7 is a schematic perspective view illustrating the releasing step of the method according to the invention;

figure 8 is a schematic front view illustrating removal of the replication master from the object and object support in figure 6b after the releasing step; and

figure 9 is a schematic view similar to figure 8 in the case of an alternative embodiment of the method according to the invention.

[0034] Figure 1 shows a perspective view of an ideal replication master 10 used for the production of aspherical optical devices, for example monolayers, bilayers or multilayers, which are used as mirrors in X-ray, EUV, synchrotron or neutron scattering research. The master 10 is typically made from metal material and is cone-shaped, so that an object, in particular an optical device deposited on the master surface will have the desired curvature for focussing and/or collimating purposes.

[0035] The optical layer deposited on the surface of the master 10 will finally be transferred to an object support 12 shown in figure 2. This object support 12 can be a rectangular block of metal or other stable material having a length corresponding to the axial length of the master 10 and being provided with a recess 14 the shape of which corresponds to a counterform of a part of the external surface of the master 10. For example, as shown in figures 1 and 2, the recess 14 in the object support 12 is approximately shaped such that it can receive half of the master 10 when inserted into recess 14, the other half of the master 10 protruding from the object support

12.

[0036] In the field of optical device production it is well-known that the idealistic representation of the master 10 having smooth surfaces in figure 1 does not correspond to reality when produced by the shaping processes described above, e.g. diamond turning. Rather the master 10 has to be imagined as having rough surfaces, as is schematically shown in the perspective view of figure 3a and in the front view of the broad end of the cone-shaped master 10 in figure 3b. Even after diamond turning the surface roughness of the master 10 will still be in an order of magnitude of approximately 20 Å. Directly depositing an optical monolayer, bilayer or multilayer on top of such a rough master 10 would yield surface and interface roughness values of the optical layer(s) in at least the same order of magnitude reducing their reflectivity to values which would prevent their use in modern optical devices for research or industrial purposes.

[0037] According to the invention, the rough master 10 is therefore coated with a smoothening layer 16. The smoothening layer 16 can for example be applied by dip-coating, i.e. dipping the master 10 into a tank containing the smoothening layer material, removing the master 10 from the tank and, if necessary, curing the thin layer 16 which adheres to the master surface, for example by special thermal treatments well-known in the art. After this hardening process the surface of the smoothening layer 16 has a much smaller roughness as the master surface on which it has been grown. The hardened and smooth surface of the smoothening layer 16 therefore forms an ideal basis for the deposition of an optical monolayer, bilayer or multilayer.

[0038] As suitable smoothening layer materials a liquid and curable polymer, in particular a PMMA photoresist can be chosen.

[0039] It is to be noted that the schematic views in figure 4a (perspective view) and in figure 4b (front view) are not to scale. In the front view of figure 4b, for example, the smoothening layer 16 surrounding the metallic master core 10a is expanded in size for illustrative purposes. In reality the thickness of the smoothening layer 16 will e.g. amount to some micrometers, so that the width of the entire master 10 is still dominated by its master core 10a on top of which the smoothening layer 16 is deposited.

[0040] Figures 5a and 5b schematically show the result of the next step of the replication method according to an embodiment of the invention. In these figures, the master 10 shown in figure 4a and 4b has, for reasons of simplicity, been coated with only one additional layer 18, for example a gold layer to be used as a reflecting mirror. This deposition of the gold layer 18 can for example be realised by a physical vapour deposition method such as magnetron sputtering deposition or ion beam sputtering or by molecular beam epitaxy (MBE) deposition or by chemical vapour deposition. In figure 5a and 5b the gold layer completely surrounds the entire circumferential surface of the master 10, i.e. the entire smoothening layer

16. However, it is generally possible to limit the deposition of the gold layer 18 to only a part of the master's surface. In this case, it is also generally possible to limit the deposition of the smoothening layer 16 on top of the master core 10a to only those regions of the master 10 which will subsequently be used for the gold layer deposition. In both cases one can obtain a highly curved gold mirror having the desired curvature for focussing and/or collimating purposes by a gold deposition on a convex replication master surface avoiding possible shadowing problems when directly depositing on the final concave substrate.

[0041] In the following steps of this embodiment of the method according to the invention, the optical layer 18 produced on top of the master 10 has to be transferred to the object support 12 shown in figure 2, more precisely into its correspondingly shaped recess 14.

[0042] For this purpose, the external surface of the optical layer 18 shown in figures 5a and 5b and/or the surface of the recess 14 are provided with an epoxy glue, the master 10 with the optical layer 18 on top is inserted into the recess 14 as schematically shown in the perspective view of figure 6a, and the glue layer forming in the recess 14 and fixing the master 10 with the optical layer 18 on top to the object support 12 is allowed to harden.

[0043] Figure 6b shows a schematic front view of the master 10 and the object support 12 after executing this glueing step according to the invention. An epoxy glue layer 20 bonds the object support 12 to the optical layer 18 surrounding the smoothening layer 16 which in turn surrounds the master core 10a. Again it has to be pointed out that figure 6b is not to scale, and that all layer thicknesses are considerably exaggerated for clarity purposes. As mentioned above, the smoothening layer 16 will for example have a thickness of several micrometers. The thickness of the optical layer 18, however, may only amount to several nanometers in case of a monolayer or some hundred of nanometers or even some micrometers in case of a complicated optical multilayer 18, for example a W/Si multilayer for X-ray crystallography or a Co/Ti supermirror to be used as a polarising mirror for neutron reflection. The glue layer 20 bonding the optical layer 18 to the support 12, however, may have a thickness of several millimeters. In a particularly advantageous embodiment of the invention the epoxy glue layer 20 may even have different thickness values at different axial positions of the master 10. This allows to avoid any time-consuming pre-shaping of the recess 14 provided in the object support 12:

[0044] In this case, the object support 12 can be provided with a simple rectangular recess 14, the length of which approximately corresponds to the axial length of the master 10, and the width of which is slightly larger than the width of the broad end of the master 10 (the right end of the master 10 in figure 1). One can then simply fill the rectangular recess 14 with epoxy glue up to a suitable level and immerse the master 10 with the optical

layer 18 on top into the glue, leading to a small width of the epoxy glue layer 20 close to the broad end of the master 10 and to a larger thickness of the epoxy glue layer 20 close to the small end of the master 10.

[0045] After hardening of the glue layer 20 the master 10 has to be removed from the optical layer 18, in order to complete its transfer to the object support 12.

[0046] This releasing step is realised by immersing the entire set-up shown in figures 6a and 6b into a tank 22 filled with a solvent, for example acetone. The solvent dissolves the smoothening layer 16, for example the PMMA photoresist. The entire set-up is then carefully taken out of the tank 22. As shown in figure 8, the optical layer 18 is still firmly bonded to the object support 12 by the glue layer 20, whereas the replication master 10 is no longer connected to the optical layer 18 as the connecting smoothening layer 16 has been dissolved. The master 10 can therefore easily be removed. It is to be noted, that the upper half of the optical layer 18 shown in figure 6b is no longer shown in figure 8. It can be cut away during removal of the master 10. As the smoothening layer 16 has been completely removed, it is not part of the final optical device and therefore not exposed to any radiation during subsequent use of the device, thus avoiding stability problems.

[0047] The master 10 can subsequently be coated with a new smoothening layer 16 in order to begin a new replication process for producing another optical device. The upper surface 18a of the optical layer 18 shown in figure 8 can now be used as a focussing reflecting mirror for X-rays or other radiation. As becomes clear by comparing figure 8 with figure 6b, this reflecting surface 18a has always been in contact with the outer circumferential surface of the smoothening layer 16, and will therefore have a small roughness of only some Å leading to a good mirror reflectivity. If the layer 18 is a multilayer, it gets clear from Fig. 8 that its topmost layers have been directly grown on the smoothening layer 16, so that these topmost layers, the adjacent layers which have been deposited on them as well as their interfaces will have excellent roughness values. This is an advantage of using such a replication method for optical purposes as generally the top layers of a multilayer have the higher potential contribution to the reflected field because of less absorption.

[0048] Figure 9 shows a front view similar to figure 8 at the end of an alternative embodiment of the method according to the invention. This alternative embodiment differs from the embodiment described in connection with figures 3 to 8 in two different aspects:

[0049] In the first place, the embodiment illustrated in figure 9 uses a smoothening layer 16 which is not attacked by the solvent in the tank 22. Instead, at the beginning of the master production process according to this embodiment of the invention, the master 10 has been coated with an additional release layer surrounding the smoothening layer 16. This release layer has later on been dissolved by the solvent in the tank 22 and is therefore not shown in figure 9.

[0050] As a further essential difference between the embodiment illustrated in figure 9 and the first embodiment described above, the object produced by replication in this alternative embodiment is not an optical layer itself, but rather the epoxy glue layer 20. In this case, the master 10 with the smoothening layer 16 surrounding the master core 10a and the release layer surrounding the smoothening layer 16 is directly coated with the epoxy or other glue in the way described above, for example by immersing the master 10 in highly flowable heated epoxy glue provided in the recess 14 of the object support 12. The epoxy glue is then again allowed to cure. After this intermediate step, the entire set-up comprising the master 10 and the object support 12 bonded to each other by means of the glue layer 20 is again immersed in the tank 22 containing a solvent which only dissolves the release layer. The master 10 still having the smoothening layer 16 on top is then removed from the object support 12 as shown in figure 9, leaving the glue layer 20 bonded to the object support 12. In this case it is the upper glue layer surface 20a of the glue layer 20 which has constantly been in contact with the outer circumferential surface of the meanwhile dissolved release layer, so that the upper surface 20a is extremely smooth and has the desired surface shape, and can therefore successfully be used as a substrate for the deposition of an optical monolayer, bilayer or multilayer. This deposition is then executed on a substrate the shape of which is a counterform of the master surface, so that after the optical layer deposition one obtains a suitably curved focussing and/or collimating aspherical mirror.

[0051] The replication master producing method according to the invention as well as the entire method for producing a smooth optical device or a smooth substrate according to the invention are not at all limited to the above embodiments. The master core 10a may have a different shape, for example any spherical or aspherical shape like an ellipsoid, a paraboloid or a cylinder, and may be made from a non-metallic material, for example glass. Similarly the object support 12 can be made by any sufficiently stable material, and the recess 14 may in general either be pre-shaped to an approximate counterform of the master 10, or may have a simpler and slightly larger shape, so that gaps between the object support 12 and the master received in the recess 14 are filled with glue during the production method according to the invention. In another embodiment, the transfer of the object, surrounding the smooth master, to the object support 12 prior to the releasing step can be done by means of molecular adhesion.

[0052] As mentioned above, the release layer used in the second embodiment illustrated in figure 9 could also be provided between the layer core 10a and the smoothening layer 16. In this case as well as in the case shown in figure 9 the smoothening layer 16 and/or the release layer may be soluble.

[0053] Furthermore it has to be pointed out that the releasing step need not necessarily be realised chemi-

cally by means of a solvent. One can conceive removing the master 10 from the object support 12 at the end of the replication method according to the invention by cooling and shrinking the master 10.

[0054] Furthermore, as explained in the introduction, the method according to the invention may comprise profilometry and/or reflectometry characterisation of an optical layer 18 deposited on the master 10. In this case the object support 12 should be chosen such as to be easily mountable in a profilometry or reflectometry apparatus, for example on a goniometer table of an X-ray reflectometer.

[0055] Finally it has to be pointed out that although in the above description of the method according to the invention, the step of coating at least a part of the master with a smoothening layer is an additional step executed after the step of treating the master surface by diamond turning, this diamond turning step for treating the master surface could also be completely skipped. Furthermore one could also execute additional surface treatment steps between diamond turning and before applying the smoothening layer, e.g. short polishing.

## Claims

1. A method for producing a replication master (10) having a surface with low roughness, comprising the steps of:

- forming said master (10) such as to have a desired external surface shape which at least partially corresponds to a counterform of a surface of an object (18, 20) to be produced by replication; and
- treating said external surface of said master (10) to obtain a predetermined surface roughness value,

### characterized in that

said method comprises the step of coating at least a part of said master (10) with a smoothening layer (16), said smoothening layer (16) being made from a material having a flowability such that the top surface of said smoothening layer (16) displays a smaller roughness than the surface on which it is formed.

2. The method according to claim 1, characterized in that said smoothening layer (16) is applied by dip-coating or spin-coating said master (10) with a liquid smoothening material and hardening said smoothening material.
3. The method according to claim 1 or 2, characterized in that it furthermore comprises the step of coating at least a part of said master (10) with a release layer.
4. The method according to any of claims 1 to 3, char-

acterized in that said smoothening layer (16) and/or said release layer is made of a soluble material, in particular a soluble polymer material, for example a PMMA photoresist.

5. A replication method for producing a smooth object (18, 20) having a low surface roughness, comprising the steps of:

- producing a replication master (10) by a method according to any of the preceding claims;
- coating at least a part of said master (10) with an object material such that the surface of said object (18, 20) corresponds to a counterform of said master (10); and
- releasing said object (18, 20) from said master (10).

6. The method according to claim 5, characterized in that said releasing step comprises dissolving said smoothening layer (16) and/or said release layer on top of said master (10) by a solvent.

7. The method according to claim 5 or 6, characterized in that it furthermore comprises the step of providing glue (20) to said object (18, 20) and/or to an object support (12) and glueing them together before executing said releasing step.

8. The method according to claim 7, characterized in that the amount of said glue (20) is chosen such as to fill gaps between said object (18, 20) and said object support (12).

9. The method according to any of claims 5 to 8, characterized in that said objects (18) is an optical device (18), e.g. a reflection or transmission monolayer, bilayer or multilayer.

10. The method according to claim 9, characterized in that it furthermore comprises the step of characterizing said optical device (18) on top of said master (10) before executing said releasing step.

11. The method according to claim 10, characterized in that said characterization step comprises performing a profilometry and/or a reflectometry measurement of said optical device (18).

12. The method according to any of claims 5 to 8, characterized in that said object (20) is a substrate (20a) for an optical device (18).

13. The method according to claim 12 when dependent on claim 7, characterized in that said object material and the material of said glue (20) are identical.

14. The method according to claim 13, characterized

in that said object material and said glue (20) comprise epoxy resin.

15. The method according to any of claims 12 to 14, characterized in that it furthermore comprises the step of coating at least a part of said master (10) with a protection layer on top of said smoothening layer (16) or release layer before applying said object material.

16. A replication master (10) for producing a smooth object (18, 20) having a low surface roughness, said master (10) having an external surface shape which at least partially corresponds to a counterform of a surface of said object (18, 20), characterized in that at least a part of said master (10) is coated with a smoothening layer (16), said smoothening layer (16) being made from a material having a flowability such that the top surface of said smoothening layer (16) displays a smaller roughness than the surface on which it is formed.

17. The replication master (10) according to claim 16, characterized in that it is furthermore at least partially coated with a release layer.

18. The replication master (10) according to claim 16 or 17, characterized in that said smoothening layer (16) and/or said release layer is made of a soluble material, in particular a soluble polymer material, for example a PMMA photoresist.

#### Patentansprüche

1. Verfahren zur Herstellung einer Replikationsmatrize (10), die eine Oberfläche mit niedriger Rauigkeit aufweist, umfassend die Schritte:

- Bilden der Matrize (10) derart, dass sie eine gewünschte äußere Oberflächengestalt aufweist, welche zumindest teilweise einer Gegenform einer Oberfläche eines durch Replikation herzustellenden Objekts (18, 20) entspricht; und
- Behandeln der äußeren Oberfläche der Matrize (10) zur Erzielung eines vorbestimmten Oberflächenrauigkeitswerts,

dadurch gekennzeichnet, dass das Verfahren den Schritt des Beschichtens wenigstens eines Teils der Matrize (10) mit einer Glättungsschicht (16) umfasst, wobei die Glättungsschicht (16) aus einem Material hergestellt ist, welches eine Fließfähigkeit derart besitzt, dass die obere Oberfläche der Glättungsschicht (16) eine kleinere Rauigkeit aufweist als diejenige Oberfläche, auf der sie gebildet ist.

2. Verfahren nach Anspruch 1, dadurch gekenn-

- zeichnet, dass die Glättungsschicht (18) aufgebracht wird, indem die Matrize (10) mit einem flüssigem Glättungsmaterial tauchbeschichtet oder rotationsbeschichtet wird und das Glättungsmaterial ausgehärtet wird.
3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, dass es ferner den Schritt des Beschichtens wenigstens eines Teils der Matrize (10) mit einer Ablöseschicht umfasst.
4. Verfahren nach einem der Ansprüche 1-3, dadurch gekennzeichnet, dass die Glättungsschicht (18) und/oder die Ablöseschicht aus einem lösba- ren Polymermaterial, beispielsweise einem PMMA-Photoresist.
5. Replikationsverfahren zur Herstellung eines glatten Objekts (18, 20) mit einer niedrigen Oberflächenrau- higkeit, umfassend die Schritte:
- Herstellen einer Replikationsmatrize (10) mit- tels eines Verfahrens nach einem der vorherge- henden Ansprüche;
  - Beschichten wenigstens eines Teils der Mat- rize (10) mit einem Objektmaterial derart, dass die Oberfläche des Objekts (18, 20) einer Ge- genform der Matrize (10) entspricht; und
  - Ablösen des Objekts (18, 20) von der Matrize (10).
6. Verfahren nach Anspruch 5, dadurch gekenn- zeichnet, dass der Ablöseschritt ein Auflösen der Glättungsschicht (16) und/oder der Ablöseschicht oben auf der Matrize (10) mit Hilfe eines Lösungs- mittels umfasst.
7. Verfahren nach Anspruch 5 oder 6, dadurch ge- kennzeichnet, dass es ferner den Schritt umfasst, Klebstoff (20) auf das Objekt (18, 20) und/oder auf einen Objektträger (12) aufzubringen, und sie zu- sammenzukleben, bevor der Ablöseschritt ausge- führt wird.
8. Verfahren nach Anspruch 7, dadurch gekenn- zeichnet, dass die Menge des Klebstoffs (20) derart gewählt ist, dass Lücken zwischen dem Objekt (18, 20) und dem Objektträger (12) gefüllt werden.
9. Verfahren nach einem der Ansprüche 5-8, dadurch gekennzeichnet, dass das Objekt (18) eine opti- sche Vorrichtung (18) ist, beispielsweise eine Refle- xions- oder Transmissions-Einfachschicht, -doppel- schicht oder -vielfachschicht.
10. Verfahren nach Anspruch 9, dadurch gekenn- zeichnet, dass es ferner den Schritt des Charakte- risierens der optischen Vorrichtung (18) oben auf der Matrize (10) vor der Durchführung des Ablöse- schritts umfasst.
11. Verfahren nach Anspruch 10, dadurch gekenn- zeichnet, dass der Charakterisierungsschritt das Durchführen einer Profilometrie- und/oder einer Re- flectometrie-Messung an der optischen Vorrichtung (18) umfasst.
12. Verfahren nach einem der Ansprüche 5-8, dadurch gekennzeichnet, dass das Objekt (20) ein Substrat (20a) für eine optische Vorrichtung (18) ist.
13. Verfahren nach Anspruch 12, bei Abhängigkeit von Anspruch 7, dadurch gekennzeichnet, dass das Objektmaterial und das Material des Klebstoffs (20) identisch sind.
14. Verfahren nach Anspruch 13, dadurch gekenn- zeichnet, dass das Objektmaterial und der Klebstoff (20) Epoxydharz enthalten.
15. Verfahren nach einem der Ansprüche 12-14, da- durch gekennzeichnet, dass es ferner den Schritt umfasst, wenigstens einen Teil der Matrize (10) mit einer Schutzschicht oben auf der Glättungsschicht (16) oder der Ablöseschicht zu beschichten, bevor das Objektmaterial aufgebracht wird.
16. Replikationsmatrize (10) zur Herstellung eines glat- ten Objekts (18, 20) mit einer niedrigen Oberflächen- rauigkeit, wobei die Matrize (10) eine äußere Ober- flächengestalt aufweist, die zumindest teilweise ei- ner Gegenform einer Oberfläche des Objekts (18, 20) entspricht, dadurch gekennzeichnet, dass wenigstens ein Teil der Matrize (10) mit einer Glättungsschicht (16) beschichtet ist, wobei die Glättungsschicht (16) aus einem Material hergestellt ist, das eine Fließfähigkeit derart besitzt, dass die obere Oberfläche der Glät- tungsschicht (16) eine geringere Rauigkeit aufweist als diejenige Oberfläche, auf der sie gebildet ist.
17. Replikationsmatrize (10) nach Anspruch 16, da- durch gekennzeichnet, dass sie ferner wenigsten teilweise mit einer Ablöseschicht beschichtet ist.
18. Replikationsmatrize (10) nach Anspruch 16 oder 17, dadurch gekennzeichnet, dass die Glättungs- schicht (16) und/oder die Ablöseschicht aus einem löslichen Material hergestellt ist/sind, insbesondere einem löslichen Polymermaterial, beispielsweise ei- nem PMMA-Photoresist.

# Revendications

1. Procédé de fabrication d'une matrice de reproduction (10) ayant une surface de faible rugosité, comprenant les étapes suivantes :

- la formation de ladite matrice (10) de manière à avoir une forme de surface externe désirée qui corresponde au moins partiellement à un moule inversé d'une surface d'un objet (18, 20) à fabriquer par reproduction ; et
- le traitement de ladite surface externe de ladite matrice (10) pour obtenir une valeur de rugosité de surface prédéterminée,

## caractérisé en ce que

ledit procédé comprend l'étape de revêtement d'au moins une partie de ladite matrice (10) avec une couche de lissage (16), ladite couche de lissage (16) étant constituée d'un matériau ayant une fluidité telle que la surface de dessus de ladite couche de lissage (16) affiche une rugosité inférieure à la surface sur laquelle elle est formée.

2. Procédé selon la revendication 1, caractérisé en ce que ladite couche de lissage (16) est appliquée par trempage ou dépôt à la tournette de ladite matrice (10) avec un matériau de lissage liquide et par durcissage dudit matériau de lissage.

3. Procédé selon les revendications 1 ou 2, caractérisé en ce qu'il comprend en outre l'étape de revêtement d'au moins une partie de ladite matrice (10) par une couche antiadhésive

4. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé en ce que ladite couche de lissage (16) et/ou ladite couche antiadhésive est constituée d'un matériau soluble, en particulier d'un matériau polymère soluble, par exemple un photorésistant PMMA.

5. Procédé de reproduction pour la fabrication d'un objet lisse (18, 20) ayant une surface de faible rugosité, comprenant les étapes suivantes :

- la fabrication d'une matrice de reproduction (10) par un procédé selon l'une quelconque des revendications précédentes ;
- le revêtement d'au moins une partie de ladite matrice (10) par un matériau d'objet tel que la surface dudit objet (18, 20) corresponde à un moule inversé de ladite matrice (10) et
- le démoulage dudit objet (18, 20) de ladite matrice (10).

6. Procédé selon la revendication 5, caractérisé en ce que ladite étape de démoulage comprend la dis-

solution de ladite couche de lissage (16) et/ou de ladite couche antiadhésive au-dessus de ladite matrice (10) par un solvant.

7. Procédé selon les revendications 5 ou 6, caractérisé en ce qu'il comprend en outre l'étape d'application de colle (20) sur ledit objet (18, 20) et/ou sur un support d'objet (12) et collage de ceux-ci ensemble avant de procéder à ladite étape de démoulage.

8. Procédé selon la revendication 7, caractérisé en ce que la quantité de ladite colle (20) est choisie de manière à remplir les espaces entre ledit objet (18, 20) et ledit support d'objet (12).

9. Procédé selon l'une quelconque des revendications 5 à 8, caractérisé en ce que ledit objet (18) est un dispositif optique (18), par exemple une monocouche, bicouche ou multicouche de réflexion ou de transmission.

10. Procédé selon la revendication 9, caractérisé en ce qu'il comprend en outre l'étape de caractérisation dudit dispositif optique (18) au-dessus de ladite matrice (10) avant de procéder à ladite étape de dé-moulage.

11. Procédé selon la revendication 10, caractérisé en ce que ladite étape de caractérisation comprend l'exécution d'une mesure de profilométrie et/ou de réflectométrie dudit dispositif optique (18).

12. Procédé selon l'une quelconque des revendications 5 à 8, caractérisé en ce que ledit objet (20) est un substrat (20a) pour dispositif optique (18).

13. Procédé selon la revendication 12 lorsqu'elle dépend de la revendication 7, caractérisé en ce que ledit matériau de l'objet et le matériau de ladite colle (20) sont identiques.

14. Procédé selon la revendication 13, caractérisé en ce que ledit matériau de l'objet et ladite colle (20) contiennent de la résine époxy.

15. Procédé selon l'une quelconque des revendications 12 à 14, caractérisé en ce qu'il comprend en outre l'étape de revêtement d'au moins une partie de ladite matrice (10) avec une couche de protection au-dessus de ladite couche de lissage (16) ou de la couche antiadhésive avant l'application dudit matériau de l'objet.

16. Matrice de reproduction (10) pour la fabrication d'un objet lisse (18, 20) ayant une faible rugosité de surface, ladite matrice (10) ayant une forme de surface externe qui correspond au moins partiellement à un moule inversé d'une surface dudit objet (18, 20), ca-

caractérisée en ce qu'au moins une partie de ladite matrice (10) est revêtue d'une couche de lissage (16), ladite couche de lissage (16) étant constituée d'un matériau ayant une fluidité telle que la surface de dessus de ladite couche de lissage (16) affiche une rugosité inférieure à la surface sur laquelle elle est formée. 5

17. Matrice de reproduction (10) selon la revendication 16, caractérisée en ce qu'elle est en outre au moins partiellement revêtue d'une couche antiadhésive. 10

18. Matrice de reproduction (10) selon l'une des revendications 16 ou 17, caractérisée en ce que ladite couche de lissage (16) et/ou ladite couche antiadhésive est constituée d'un matériau soluble, en particulier d'un matériau polymère soluble, par exemple un photorésistant PMMA. 15

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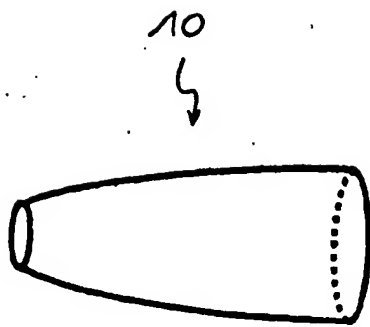


Fig. 1

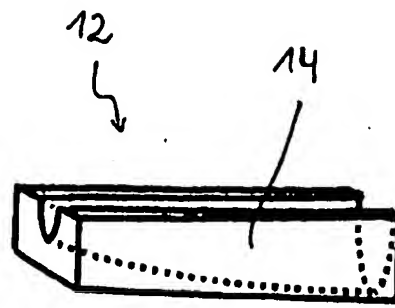


Fig. 2



Fig. 3a



Fig. 3b

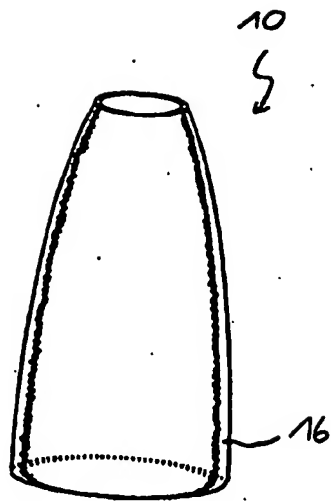


Fig. 4a

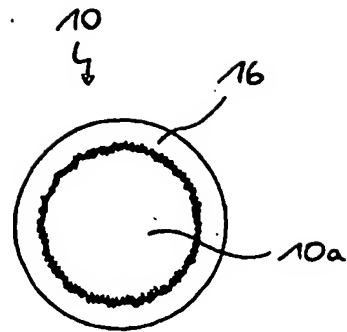


Fig. 4b

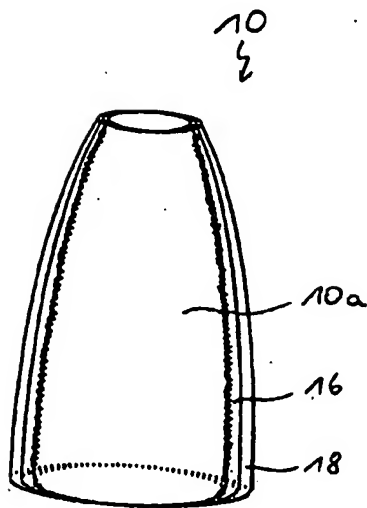


Fig. 5a

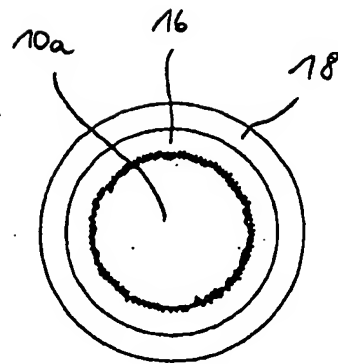


Fig. 5b

Fig. 6a

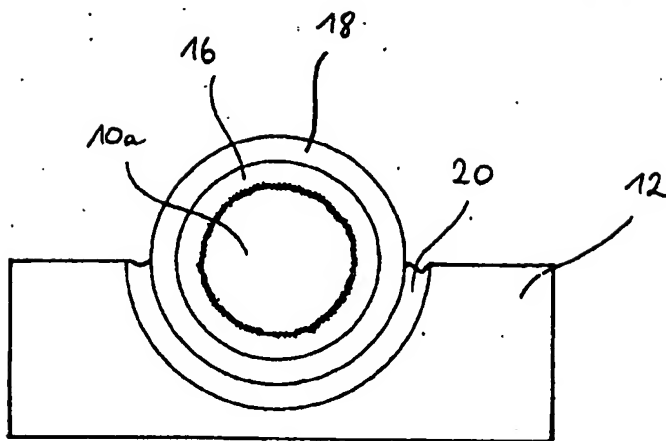
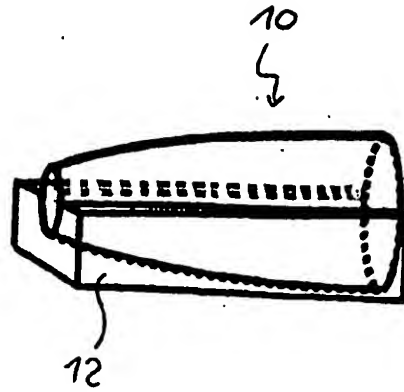


Fig. 6b

Fig. 7

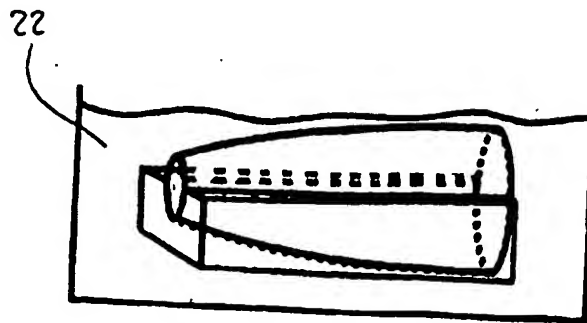


Fig. 8

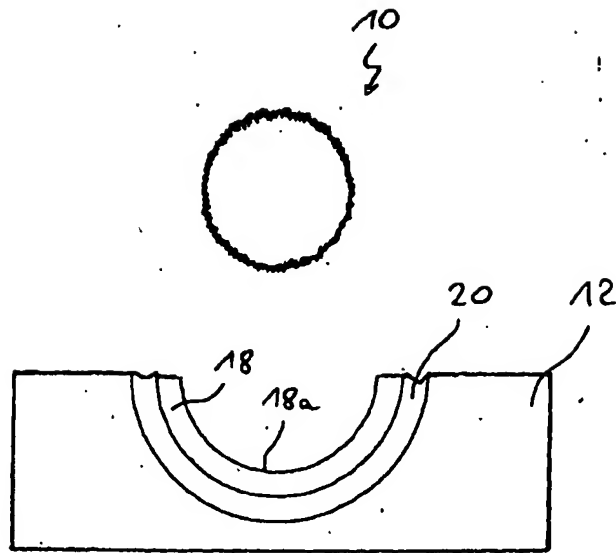
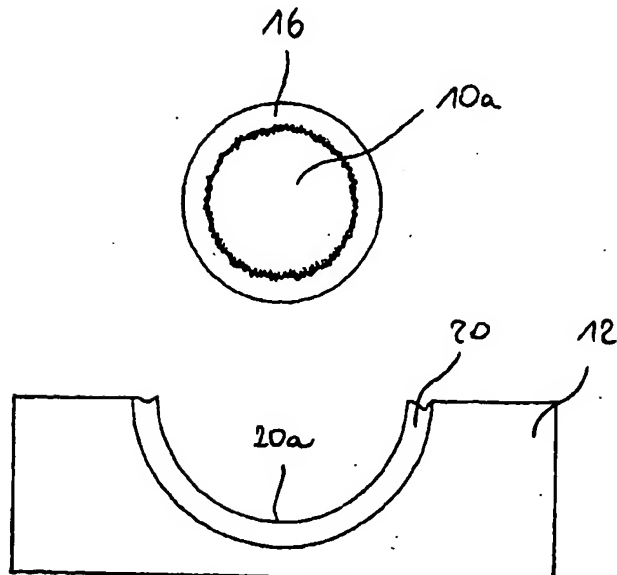


Fig. 9



**REFERENCES CITED IN THE DESCRIPTION**

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